Update on Insertion and Complications of Central Venous Catheters for Hemodialysis

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Abstract

Central venous catheters are a popular choice for the initiation of hemodialysis or for bridging between different types of access. Despite this, they have many drawbacks including a high morbidity from thrombosis and infection. Advances in technology have allowed placement of these lines relatively safely, and national guidelines have been established to help prevent complications. There is an established algorithm for location and technique for placement that minimizes harm to the patient; however, there are significant short- and long-term complications that proceduralists who place catheters should be able to recognize and manage. This review covers insertion and complications of central venous catheters for hemodialysis, and the social and economic impact of the use of catheters for initiating dialysis is reviewed.

Keywords
- hemodialysis
- central venous catheters
- complications
- techniques

Objectives: Upon completion of this article, the reader will be able to discuss the technical considerations, outcomes, and complications of intravascular catheters placed for hemodialysis.

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Central venous catheters (CVCs) are used to provide adequate hemodialysis (HD) in patients who are initiating dialysis or are awaiting maturation of more permanent vascular access such as an arteriovenous fistula (AVF) or (less desirable) arteriovenous graft (AVG). They have the advantage over other types of HD access in that catheters are relatively safe and easy to place, provide quick access in urgent situations, and can serve as a bridge to other, more reliable but more invasive forms of access. They can also serve as a last resort when all other options have been exhausted. However, there are many drawbacks to catheter use. The National Kidney Foundation, Kidney Disease Outcomes Quality Initiative (NKF-KDOQI) states that less than 10% of HD patients should be dialyzed chronically with a tunneled catheter.[1] Despite this, catheters remain popular for both incidence and maintenance HD.

Advantages and Disadvantages of CVC for HD

CVCs for HD are universally applicable, meaning they can be placed in almost everyone, and there are many benefits of using catheters for HD; there are a variety of sites for placement and they are immediately available for use; they are relatively low cost and easy to place and replace; venipuncture is not required for dialysis; and thrombotic complications are relatively straightforward to correct. Unfortunately, catheters also have many drawbacks, including having the highest morbidity of all accesses due to thrombosis and infection; causing central venous stenosis and occlusion; the external hubs are disfiguring and cause

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low patient satisfaction; and their relatively lower blood flow rates demand longer dialysis times.[2]

Types of Catheters

CVCs for HD are for either temporary (typically used for fewer than 21 days) or permanent access. Temporary catheters are smaller in size, are placed directly into the vein, and come in two- or three-lumen designs. The three-lumen designs in particular are helpful in patients who require urgent HD and/or may require other medications. The addition of the third lumen allows concomitant administration of fluids, antibiotics, and resuscitative medicines without having to place other lines for access. The third lumen often is rated for power injection during imaging studies, again adding to the versatility of the device in the acute setting.

Permanent HD catheters, in contradistinction, are larger, have a cuff that is tunneled under the skin away from the vein puncture site, and are only available with two lumens. Over time, the cuff initiates an inflammatory response, creating a scar, which affixes the catheter under the skin and prevents easy traction withdrawal. The catheter course under the skin also prevents bacteremia. There are a variety of catheters currently on the market, presenting a crowded marketplace. No one catheter has proven superior over its rivals, despite trials comparing various designs.[2–7] Patients who present with acute renal failure and then go on to chronic renal failure pose a particular problem in initiating access. These patients often receive a temporary catheter in the hope that their kidneys will recover. If that does not occur, a common strategy that has been shown to be effective is the transition from a temporary to a permanent catheter utilizing the same entry site into the vein[8]; this conversion preserves access to the central veins in patients with limited options.

There has been a lot of interest in developing different tip designs since the original Hickman Pheresis catheter debuted (Bard, Inc.; Salt Lake City, UT). The original design has a "stepped" tip and is made of silicone. The stepped design was supposed to reduce recirculation; however, those rates remained high. Subsequently, split-tip and symmetric-tip catheters have been developed. These are designed to reduce recirculation and resist growth of fibrin sheath; the reader is directed toward a previous well-researched review, as catheter designs and fluid dynamics are beyond the scope of this review.[2] Finally, there is considerable interest in catheters coated with antibiotics or heparin for reduction in infectious and thrombotic complications.[9]

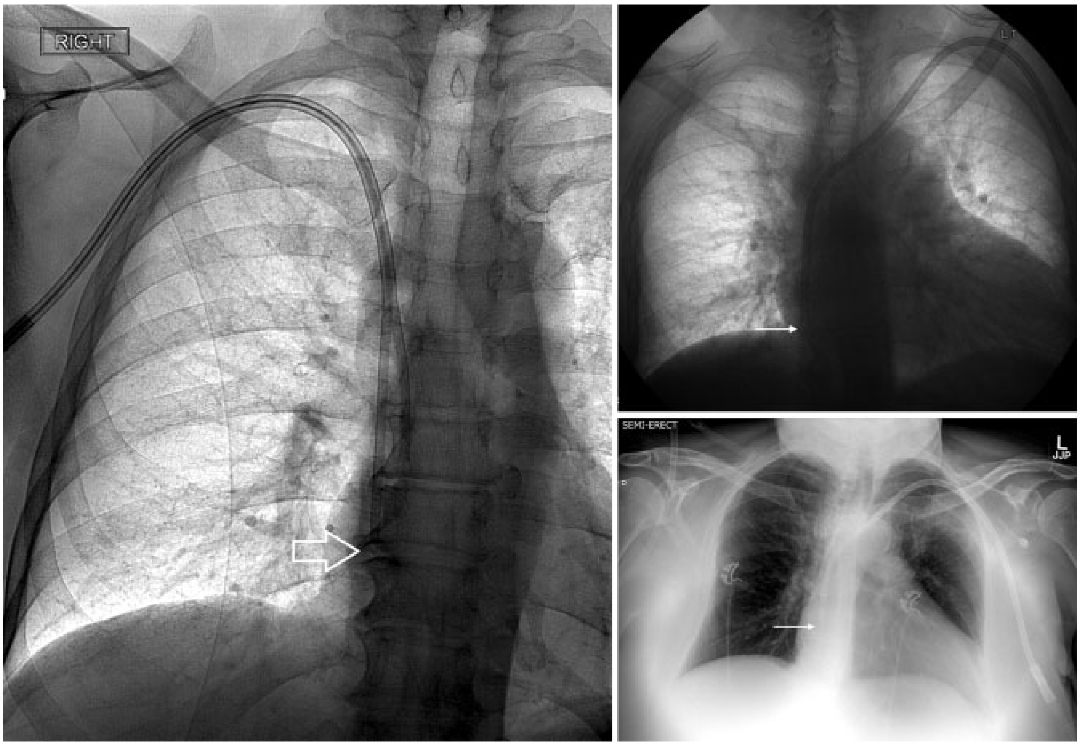
Insertion Technique

Insertion of CVC for HD is a relatively straightforward procedure for both temporary and permanent catheters. The universal availability of ultrasound and fluoroscopic guidance has resulted in recommendations from NKF-KDOQI regarding the use of both technologies for placement of cuffed, tunneled catheters.[1]

There are well-established guidelines for selection of an insertion site for CVC. The preferred site is the right internal jugular (IJ) vein, low in the neck and close to the jugular bulb so that there is little chance for catheter kink when tunneling to the chest wall. The vein course from the right IJ vein to the superior vena cava (SVC) is straight and short when compared with other access sites, allowing a shorter catheter and higher flow rates (►**Fig. 1a**). When the right IJ is occluded, the right external jugular (EJ) vein should be used before attempting access on the left side.[10] The left IJ is the third choice, and is a technically challenging approach owing to the tortuous course from the left IJ to the SVC. Careful placement deep within the right atrium (RA) is essential to prohibit catheter malposition and malfunction, as after placement the catheter tends to retract out of the RA and may migrate as far as the innominate veins in patients with high mass body index (►**Fig. 1b**). Once the IJ and EJ are exhausted in patients, other alternatives can be entertained, such as subclavian veins; however, it is well known that CVCs placed into the subclavian vein have a high likelihood of subsequent venous occlusion or stenosis,[11] which can have disastrous effects in patients who require patent central veins from their arms for functional AVF or AVG. This guideline is explicitly detailed in the NKF-KDOQI guidelines.[1] Therefore, the subclavian veins are utilized as a last resort in patients who have no other upper extremity access.

Alternative access sites include femoral, translumbar, transhepatic, and transrenal veins, whose success has been reported in the literature, but is beyond the scope of this review.

Access to the jugular vein with ultrasound guidance is accomplished through two routes: the in-plane (IP) and the out-of-plane (OP) approach. For both approaches, a high frequency (7–17 MHz) linear transducer ultrasound probe is used. The OP route is a direct descendent of the landmark technique, where a blind approach to the jugular vein was guided by muscular and bony landmarks. In this approach, the needle and vein are both placed in a transverse plane to the linear transducer. The operator inserts the needle cranial to the transducer at a 45-degree angle. As the needle is advanced, the operator scans in a sweeping motion in a cranial-caudal direction to guide the needle tip into the vein, keeping both the IJ and the carotid artery in view. The needle tip is seen as a bright "star" as it passes through the tissues, tents the wall of the IJ, and enters the vein (►**Fig. 2a**). Careful technique must be used to avoid passing the needle through the back wall of the vein and into structures such as the subclavian artery and pleura. In the IP route, the transducer is placed transverse to the vein, allowing visualization of the IJ and the carotid at all times, but in this approach the needle is inserted at the side of the linear transducer. This approach allows full visualization of the entire needle from skin to vein (►**Fig. 2b**). The transducer is held at a 10- to 15-degree angle with the lateral aspect of the transducer in a more cephalad position, so that the needle is pointed to the patient's opposite side nipple. This will ensure that the wire will be directed caudally into the SVC as opposed to cranially after the IJ is accessed. One advantage to placement with the IP approach is that one can enter more caudally into the vein from a lateral approach, which makes a straighter course for tunneling. This tends to be more comfortable for the patient, because the catheter (upward of 15.5F) passes behind the sternocleidomastoid muscles instead of between them as in



a b c

Fig. 1 (**a**) Position of properly placed right internal jugular dialysis catheter. (**b**) Initial placement of left IJ catheter in obese patient. Note the placement of catheter tip deep in the right atrium (arrow). (**c**) Chest radiograph of same patient in **b** 24 hours after placement showing significant retraction of the catheter tip (arrow). This patient eventually presented with poor flows 2 weeks later, necessitating catheter exchange.

the OP approach. This difference is particularly noticeable to patients when they turn their heads.

Once access has been obtained into the IJ and the wire has been advanced into the SVC, it is essential to make a precise measurement of the distance from the entry site to the mid-RA. It is crucial to make sure the tip of the catheter resides in the highest flow channel (the RA and cavoatrial junction), for optimum performance by the catheter. Most HD catheters have specialized tips that cannot be cut and come in predetermined lengths, necessitating accurate determination of the patient's anatomy to place the correct length catheter (►**Table 1**). Lengths are reported in centimeters from tip to cuff, and are relatively standardized across brands. On posterior-anterior fluoroscopy, the SVC-RA junction can be estimated at two vertebral bodies or 4 cm below the carina.[12–14] It is important to measure using a wire or dilator to calculate the distance from the entry site to the desired tip position, which should be the middle of RA for dialysis catheters. To ensure a proper length tunnel, the cuff should be at least 4 cm from the entry site and the exit site 2 cm from the cuff. If the tunnel is too long, there is greater chance for catheter migration and kinking; if it is too short, the cuff will be above the clavicle and cause irritation to the patient. A standard of 4 cm with the tunnel in the deltopectoral groove and a cuff 2 cm from the exit site will consistently produce comfortable catheters for the patient as well as easier eventual removal of the catheter when it comes to dissect the cuff.

Once the measurement has been obtained and the proper length catheter chosen, there are two options for catheter tunneling: antegrade and retrograde. Catheters designed for antegrade tunneling come fully formed with the hub attached. The tip of the catheter is attached to a tunneling device, passed through an incision on the chest wall in the deltopectoral groove, and pulled through to the neck incision. The cuff is positioned inside the tunnel at the location described previously. The tunneling device is removed and the catheter is placed through a peel-away sheath into the vein and advanced to the level of the RA. The peel-away sheath is removed and the catheter adjusted for kinks or malposition using fluoroscopic guidance. The catheter exit site distance away from the venous entry site is chosen based on the length of catheter chosen minus the distance from the IJ to the RA plus 2 cm.

For instance, if the measurement obtained using fluoroscopic guidance is 17 cm, then a catheter with a tip-to-cuff length of 23 cm is chosen. When placed, the cuff will be 6 cm from the entry site and the exit site needs to be 2 cm from that; therefore, a distance of 8 cm is then chosen for the exit site (23 cm – 17 cm + 2 cm = 8 cm) (►**Fig. 3**).

For the retrograde tunneling technique, the catheter is manufactured so that the hub is separated from the catheter and must be attached after tunneling. For this technique, the catheter tip is placed through the peel-away sheath. Once the sheath has been removed, the tip of the catheter is adjusted to the mid-RA under fluoroscopic guidance. The catheter is folded over the clavicle and the exit site is chosen based on a mark on the catheter. A chest wall incision is performed and the tunneling device (without catheter) is advanced from the chest wall to the neck incision at the insertion site. The back of the catheter is subsequently attached to the tunneling device and pulled back through the tunnel; the catheter is cut and the hub attached. The

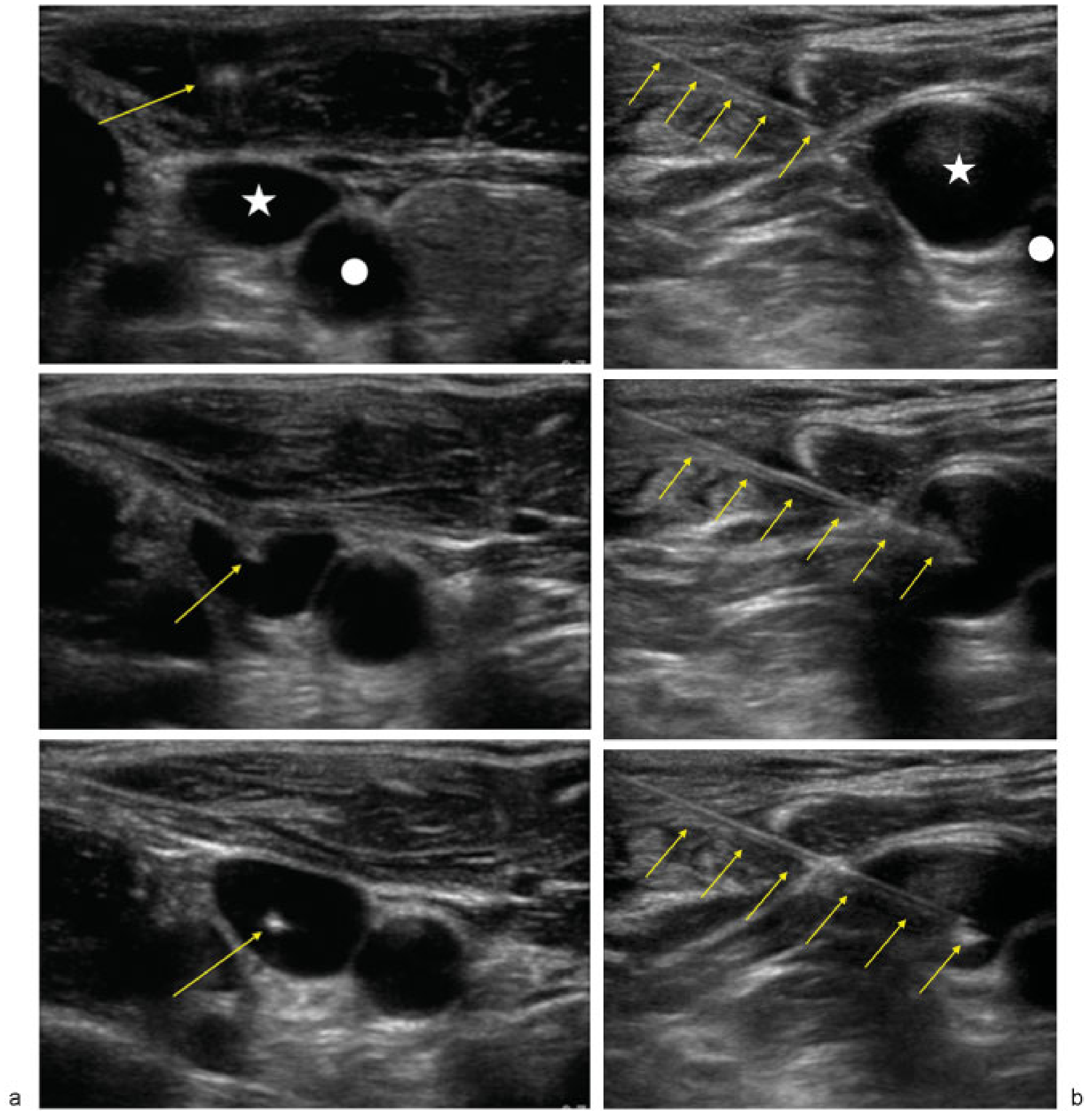


Fig. 2 (**a**) Three image captures from out-of-plane ultrasound-guided needle placement into the right internal jugular vein. The IJ (white star) and carotid (white circle) are seen. The needle appears as a bright dot (yellow arrow) as it is advanced toward the vein. (**b**) Three-image captures from in-plane ultrasound-guided needle placement into the right internal jugular vein. The needle (yellow arrows) is clearly visible throughout its course from the skin to the IJ (white star). The carotid (white circle) is medial.

retrograde technique has, in the authors' opinion, several advantages over the antegrade technique: the tip position is established first and therefore is consistent; the cuff is almost always 2 cm from the exit site, which avoids having to perform a cut down when the catheter is removed; the cuff never passes through the exit site, which means the incision can be much smaller preventing bleeding and accidental removal of the cuff before it is incorporated; and as the hub is detachable, cracked or broken clamps or hubs can be replaced without disturbing a functioning catheter. Despite these advantages, the antegrade technique is most commonly utilized in the United States.

Complications

Short Term

There are several minor and major complications that may occur during or immediately after placement of the catheter. With ultrasound and fluoroscopic guidance, and careful technique and attention to detail, these are relatively uncommon. Most complications are identified with fluoroscopic guidance, and it is essential to obtain radiographic confirmation of any CVC placement. A summary of early complications is outlined in ►**Table 2**.[15–18]

Pleural Puncture

Pneumothorax and hemothorax can occur when the needle inadvertently punctures the pleural space. This can occur when landmark techniques are used for IJ and subclavian punctures, but are exceedingly uncommon when IP approach to the jugular vein with ultrasound is utilized. Careful planning is recommended when placing CVC in patients with cystic fibrosis or chronic obstructive pulmonary disease, as their increased lung volumes can force the pleural space up above the clavicles. When using fluoroscopic guidance, a final spot radiograph of the entire

Table 1 Comparison of entry site with right atrial distance, and catheter lengths

Measurement (cm)	Tip-to-cuff length (cm)
<11 cm	15 cm (pediatrics)
11–15 cm	19 cm
15–19	23
19–23 (4[a])	27 (or 28[a])
>28	31, 33, 35
Translumbar	31, 33, 44, 50, 55 (depending on patient)
Femoral	31, 33, 44, 50, 55 (depending on patient)

[a]Manufacturer differences

Table 2 Thresholds for early complication from image-guided catheter placement

Event	Frequency (%)
Hemorrhage/hematoma	<2
Catheter malposition/kinking	<1
Venous perforation	<1
Infection	<1
Arterial puncture	<1
Pneumothorax	0–1
Air embolism	0–1

Source: Adapted from Bhutta and Culp, 2015.[15]

chest and catheter will help with recognition of complication pneumothorax, which may need a chest tube for treatment.

Arterial Puncture

Inadvertent arterial punctures have been minimized or even eliminated with ultrasound guidance in experienced hands. The use of compression helps guide the operator toward the jugular vein, and color Doppler can be used for complicated anatomy. It is essential to use the correct depth and gain on the ultrasound machine so that the anatomy is clearly defined. In dialysis patients, tortuous arteries caused by high blood pressure, obesity, and previous central venous cannulation all contribute to difficulties encountered when accessing the vein. There are strategies to avoid arterial puncture. First, identification before prepping of potential issues is essential. A pre-procedural ultrasound scan of the neck should be performed before all catheter placements and before preparing the patient. Next, using a micropuncture needle allows the operator to minimize trauma should the artery be inadvertently punctured. After placement of the micropuncture needle and wire, visualization of the wire with fluoroscopy is an easy method of ensuring venous placement. If there is malposition of the wire, access can be removed and hemorrhage controlled (in most cases) with firm pressure. If arterial puncture occurs and the catheter is placed into the artery, the complication should be recognized under fluoroscopy; if there is a question based on the radiograph, transducing the catheter for arterial versus venous pressure will help. If not recognized and dealt with immediately, this complication can have devastating side effects.

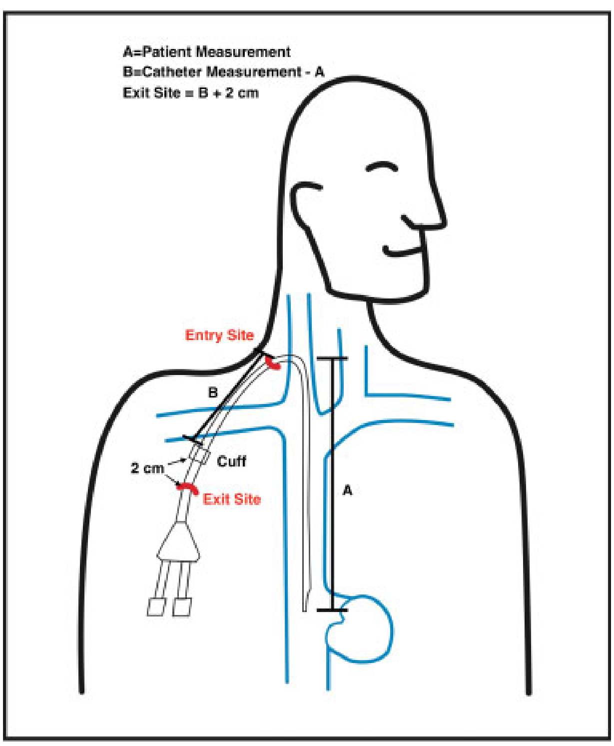


Fig. 3 Cartoon by the author, showing measurement calculation for antegrade tunneling technique.

Bleeding

Bleeding is relatively uncommon, even in patients with uremia and dysfunctional platelets. Bleeding from the entry and exit sites can be ameliorated in almost all situations with pressure. Correction of coagulopathy and thrombocytopenia before tunneled catheter placement can reduce the incidence of bleeding from the tunnel site. Uncommonly, patients may present with bleeding from their newly placed catheter site due to uremia or misadministration of heparin during flushing of the catheter. Prompt recognition of the cause will direct treatment. If the patient's partial thromboplastin time is not elevated, then a dose of desmopressin (DDAVP) is effective approximately 50% of the time in stopping hemorrhage caused by platelet dysfunction in uremic patients. Other strategies include a topical hemostatic agent or thrombin injected in the tunnel tract, which may carry a risk of introducing a tunnel infection.

Arrhythmias

Placement of the wire into the RA, or more preferably guidance into the inferior vena cava (IVC), will confirm placement of the wire within the SVC (as opposed to the azygous vein) and will provide stable access for dilating and placement of the catheter. Having the tip of the wire below the diaphragm in the IVC ensures that movement of the tip will not irritate the atrioventricular node.

All patients undergoing CVC placement should be placed on cardiac monitoring. The wire, dilator, or catheter can irritate the atrioventricular node and produce supraventricular tachycardias. This is recognized by sudden increase in the heart rate with a narrow QRS complex. Often, withdrawal of the wire or catheter back into the SVC will halt the tachycardia. Patients may remain asymptomatic or may develop syncope, hypotension, and/or chest pain. Initial treatment is through vagal maneuvers (having the patient cough, perform a Valsalva, or raise the legs). Carotid massage can be performed in younger patients, but is not recommended in elderly patients due to the possibility of inducing stroke. Treatment is conservative as long as the patient is stable; however, hypotension should prompt treatment with adenosine. Six milligrams of adenosine is given as a rapid intravenous push (use a central catheter if possible, including the newly created access), which can cause a disruption of the tachycardia and may reset the reentry loop. Adenosine injection can be repeated and the dose increased to 12 mg. Eventually, if the patient deteriorates, synchronized carotid version may be indicated.

Air Embolism

As in other immediate complications, technological advances have decreased the risk of air embolism. The widespread use of valved peel-away sheaths prevents air embolism when the catheter is placed. Before such sheaths were ubiquitous, the operator had to be wary of the possibility of introducing a large volume of intravenous air. Several strategies were employed to prevent this complication. The first maneuver was placing the patient in a reverse Trendelenburg position, which increased the intrathoracic pressure. Second, the patient's intrathoracic pressure could be controlled by either having the patient suspend breathing or hum while placing the catheter. Third, direct over-the-wire techniques were advocated, eliminating the need for a large peel-away sheath.

If these techniques fail, and the patient suffers an air embolism (often recognized by a sucking sound through the sheath as the patient breathes in), prompt response is required as the deterioration of vital signs may be delayed. Moderate size air emboli lodged in the main pulmonary artery can be seen with fluoroscopy. Placing the patient on 10 L of oxygen through a 100% non-rebreathable mask is usually all that is required. If the patient suffers a very large embolism, the RA or ventricle can become "air locked," leading to sudden cardiovascular collapse. If this occurs, the patient should be placed left side down, which attempts to move the air to the RA; vigorous suction should be applied to a catheter placed in the RA. Fortunately today, with the use of valved peel-away sheaths, this complication is minimized.

Laceration of Central Veins

Careful technique needs to be employed when dilating and directly placing catheters over a wire. Firm back tension needs to be placed on the wire while dilating, preferably with the operator's hand braced against the patient or procedure table. This will prevent the guidewire and dilator moving as a unit, which risks perforating or lacerating the sidewall of the vein. This most often occurs when trying to dilate from the left IJ through the tortuous innominate vein, but can happen any time the dilator and wire are advanced simultaneously. Such lacerations can be devastating, resulting in hemothorax or cardiac tamponade.

If the wire is placed only to the level of the RA, instead of the IVC below the diaphragm, the wire could be in the azygous vein. On posterior-anterior fluoroscopy, the course of the wire is confusing. Placing the wire below the diaphragm in the IVC ensures that when dilating, the azygous vein has not been inadvertently catheterized and at risk for laceration. If venous rupture occurs, prompt recognition and treatment with a chest tube is essential.

Long-Term Complications

Infection

The most common indication for removal of a HD CVC is infection. Infection can be categorized as exit site, tunnel, or catheter-related bacteremia (CRB). Overall, the rate of CRB with cuffed, tunneled HD CVC is 1.6 to 5.5 episodes/1,000 catheter days.[19,20] An in-depth review of this subject is beyond the scope of this article.

Catheter Malfunction

Catheter malfunction can be categorized according to etiology, many of which can be reduced with careful attention to placement technique, especially tip position within the RA. The most common etiologies include the following:

- Fibrin sheath formation
- Thrombus within catheter
- Catheter kinks
- Catheter fracture or disconnection
- Catheter malposition or migration
- Catheter tip adherent to vessel wall

Fibrin Sheath

Fibrin sheaths begin to form at the catheter entry site into the vessel as an inflammatory response to the presence of a foreign body. The cellular matrix begins with smooth muscle cells, thrombus, and endothelial cell populations. In an animal model, fibrin sheaths are present with varying degrees in 100% of catheters within 7 days. As the catheter remains in place, the sheath becomes more collagen based and eventually becomes an endothelium indistinguishable from the adjacent vein wall. In addition, 100% of fibrin sheaths are colonized with bacteria.[21] Catheter malfunction occurs as the sheath grows to cover side holes, the tip of the catheter, or if the catheter tip becomes adherent to the vein wall. The hallmark clinical indication of a fibrin sheath is the ability to flush a catheter but not aspirate. Theoretical designs of HD CVC have been proposed to prevent fibrin sheath–related malfunction, including split tips, symmetrical tips, and special coatings such as heparin and antibiotics. Treatments of fibrin sheaths include catheter stripping with a snare, catheter exchange, and catheter exchange with balloon disruption of the sheath.[22] In the dialysis population, it is especially important to adopt a vein preservation strategy when catheters malfunction. Keeping this in mind, catheter exchange with disruption of fibrin sheath has been shown to be an acceptable strategy.

Thrombosis

Thrombosis causing catheter malfunction can occur either within the catheter lumen or within the vessel lumen. All thromboses are believed to be related to fibrin sheaths. Thrombosis of the catheter is recognized by the inability to aspirate or flush a catheter. Treatment with recombinant tissue plasminogen activator (r-TPA) is the most common first line of treatment and consists of filling the lumen of the catheter with r-TPA. The TPA is allowed to dwell for 1 to 4 hours. If this fails, exchange of the catheter is recommended, although some operators will first attempt an r-TPA infusion through the catheter. Prevention of thrombosis is usually achieved by filling the lumen of the catheter with an anticoagulant (heparin or citrate) with or without antibiotic (gentamycin). Thrombosis of the vessel around the catheter is more serious and is usually related to hypercoagulable states (such as cancer), or poor tip position. Vascular thrombosis is again believed to be related to fibrin sheaths. Intravascular thrombosis is usually asymptomatic and only declares itself with catheter malfunction. Severe cases can result in arm or neck swelling, or SVC syndrome. Anticoagulation, with or without removal of the catheter, is the first-line treatment, with thrombolysis reserved for severe cases. Although catheter removal may be necessary, access site preservation is vital in this population and should be considered in all cases.

Tip Malposition

Initial catheter tip malposition should not occur with experienced operators using image guidance. One of the goals of placement of a HD CVC is to provide a catheter with the tip in the RA capable of adequate HD. Tip positions outside of the RA can lead to fibrin sheath formation, thrombosis, and central venous stenosis, as a result of poor flows or occlusion. It is well known that catheters from a left-sided approach migrate farther back with the patient in an upright position and soften the catheter after placement, and therefore result in catheter malfunction (►**Fig. 1c**). For this reason, the authors endorses placing left-sided catheters deep within the RA on initial placement (~2 cm deeper than initial right-sided placement). This will keep the tip within the RA when the inevitable migration occurs.

Central Venous Stenosis

The interplay between fibrin sheath, thrombus formation, and central vein stenosis cannot be overestimated. Each of these factors is interrelated and result in diminished HD access over time for patients with long-term CVC. There are several endovascular techniques used for maintaining patency in the central veins, but prevention should be the main goal. This means using alternatives to catheters, when catheters are necessary to use proper tip location and minimize dwell times.

Outcomes

Despite mandates from NKF-KDOQI and the Fistula-First initiative, 82.6% of new HD patients initiate HD with a CVC instead of a graft or fistula. The rate of mortality differences between patients started on AVF or AVG and CVC is staggering, as is the cost of treatment. Using an example from a recent article by Malas et al, if all 115,000 patients who started dialysis in 2010 had received fistulae, close to 14,000 lives could have been saved.[23] Clearly, the incentives for reducing CVC use for initiation of HD are not strong enough.

Conclusion

Although it is clear that HD CVCs are not desirable for long-term HD, the majority of patients who start HD do so with a catheter. Recent technologic advances and catheter designs have increased the efficiency and safety of placement and maintenance of CVC; however, they are not an ideal long-term solution. As long as catheters remain a prevalent method of providing HD, it is incumbent upon practitioners who place these devices to understand the methods for safe placement, recognition of complications, and adherence to guidelines that are designed to protect patients.

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